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# OPPORTUNITIES FOR ELECTROTECHNOLOGIES: DRYING APPLICATIONS IN ONTARIO INDUSTRY

S.J. Oda

A review of published material on electrotechnologies for industrial drying applications has identified promising opportunities for new marketing and research and development initiatives. This report contains an overview and an appendix that details the rationale for the selection of these opportunities.

## INTRODUCTION

Electric drying technologies like microwave, radio-frequency and infrared offer significant process benefits that are well recognized. In Ontario, a number of drying opportunities are available to utilize the special characteristics of electrotechnologies for undeniable customer benefit. The opportunities that are described in detail in Appendix 1 provide a basis for Ontario Hydro to focus its efforts through technology transfer and further research and development.

## OVERVIEW

The study identified 43 drying processes that are tabulated in a matrix of drying application versus industry segment. From the matrix entries technology transfer and further R&D opportunities were selected based on undeniable customer benefit as well as economic and industry health factors. A project summary sheet at the beginning of the appendix lists these applications and provides an Ontario Hydro perspective of the study.



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Product drying by electrotechnologies will have **no significant load impact** on Ontario Hydro in the future. In fact, because process time can be significantly reduced, **electrical demand and energy reductions are possible** based on the decrease in electricity use for conveyors and fan drives alone. For example, in pasta drying, the direct electricity requirement for conventional dryers is about 40% greater than the microwave systems because of the large electrical demand of the fans and conveyors. In another example, retrofitting energy-efficient, variable-speed drives to the fans in lumber dry kilns represents an opportunity with an electrical savings potential of at least 30%. By incorporating these devices into 'quality-wood' kilns, a demand reduction of 2 to 3 MW is possible[1]. Transfer of the technology to kilns drying construction-grade lumber is expected to at least double this reduction.

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[1] A. Chow and R. Solczyk, "Heat Pump Dehumidifier Efficiency Improvement Evaluation", Ontario Hydro Research Division Report No. 90-90-K, May 1990.

## APPENDIX 1

## Opportunities for Electrotechnologies:

## Drying Applications in Industry

# Opportunities for Electrotechnologies:

# Drying Applications in Industry

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# PROCESS APPLICATION REPORT SUMMARY

SUBJECTS

Drying / microwave / radio-frequency / infrared / heat pumps / superheated steam / productivity /

TOPICS

Electrotechnology / Customers - Industry / Process / Drying

AUDIENCE

Industrial customer service and marketing personnel

## Opportunities for Electrotechnologies: Drying Applications in Ontario Industry

Electric drying technologies offer significant process benefits that are well recognized. In Ontario, a number of drying opportunities are available to utilize the special characteristics of electrotechnologies for undeniable customer benefit. This study provides a basis for Ontario Hydro to investigate these opportunities through technology transfer and further research and development.

BACKGROUND

The application of electrotechnologies in Ontario industry is becoming more widespread for various reasons including better process control, improved product quality, increased production rates and lower operating costs. By helping to improve the productivity and competitive position of the manufacturing sector, electrotechnologies are an important tool that will continue to enhance the health of the Ontario economy. This document represents the first of four reports describing technology transfer and research and development opportunities for drying. Other reports describe opportunities for curing, non-metallic heating and heat recovery.

OBJECTIVE

To identify, analyze and report through an extensive review of published overview documents, significant opportunities for electrotechnologies in drying processes.

APPROACH

Published material was acquired from a number of sources including EPRI, the Gas Research Institute (GRI), Ontario Hydro (Research Division and Product Knowledge Centre), the Canadian Committee on Electrotechnologies (CCE), the International Union for Electroheat (UIE) and the Canadian Electrical Association (CEA). Using documented findings from these sources, a comprehensive matrix was assembled to summarize the information. Selection criteria were applied to the matrix entries to target a particular application for technology transfer or further research and development. All of the applications were required to provide undeniable benefit(s) to the customer. In addition, the selection criteria also considered replication potential in Ontario, possible energy/demand reductions, environmental benefit(s), and the overall health of the industry.

RESULTS

This study reviewed 80 key documents from which 43 drying processes were identified and tabulated in a matrix of drying application versus industry segment. The matrix contains drying processes in all major industry segments in the following categories: application description; current technology (if not electric); electrotechnology alternative; limitations of the electrotechnology; identification of an electrotechnology commercialized elsewhere but not in Ontario (technology-transfer needs); unresolved problems or questions requiring answers before technology transfer can take place (R & D needs); potential for replication in Ontario; key literature references describing the application; and, trade allies (eg, companies, industry and university research organizations) for possible future collaboration.

This study identified the following technology transfer opportunities: moisture profiling of fine paper using high intensity infrared heating; microwave/vacuum drying of pharmaceutical granules; drying of textiles with infrared or radio-frequency heating; and, drying of animal waste using mechanical vapour recompression (MVR) together with a conventional multiple-effect evaporator.

The following research and development opportunities were identified: superheated-steam drying of particles used in manufacturing wafer and particle board; variable speed fans for dehumidification wood-drying kilns; drying of polymer pellets using microwave or radio-frequency heating combined with hot air; drying of gypsum wall-board using radio-frequency heating together with direct-fired forced air ovens; and, drying (or dehydration) of food products.

ONTARIO HYDRO PERSPECTIVE

The corporate goal of improving the energy efficiency of Ontario industry requires an understanding of the growth potential and subsequent load impact that electrotechnologies will produce over the next fifteen years. Drying in industrial processes is dominated by natural gas-fired technologies. The amount of electricity used in industry for both drying and curing applications is less than one-fourtieth of the natural gas used for the same purpose. Drying electrotechnologies will be restricted to niche application areas where there are significant benefits to the industrial customer. These applications, while numerous, will have minimal load impact on Ontario Hydro in the future. In fact, because process time can be significantly reduced, electrical demand and energy reductions are possible based on the decrease in electricity use for conveyors and fan drives alone.

This project, which looks at the use of electrotechnologies for drying in Ontario industries, shows that growth is occurring as Ontario industry struggles to maintain its competitive position in the world marketplace. As this study shows, there are a number of opportunities for applying electrotechnologies in industrial drying processes that lead to undeniable benefits for the industrial customer. A matrix of drying applications and electrotechnologies is provided from which a short list of drying opportunities is extracted to target both technology transfer and further research and development. This document will help industrial technology and products staff and market planners understand what the current and future potential is for drying electrotechnologies in Ontario industry.

PROJECT TEAM

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## ABSTRACT

An extensive review of published material on electrotechnologies for industrial processes has been undertaken to identify promising applications for new marketing or research and development initiatives. The processes included in this review are drying, curing, heating of non-metallic materials and heat recovery. This report presents the rationale for the selection of nine promising drying opportunities for future technology transfer and research and development projects.

# 1 INTRODUCTION

For various reasons such as better process control, improved product quality, requirements for lower temperature, increased production rates and lower operating costs, electrotechnologies are seeing and will likely continue to see increased application in Ontario industry in various processes such as curing, drying, heating of non-metallic materials and in heat recovery.

## 1.1 Background

While a significant amount of published material exists, from various sources, on the subject of industrial electrotechnology application, there is a need to synthesize, analyze and organize the key information into a format which would be useful to Ontario Hydro for planning both marketing initiatives and research and development projects. Studies were funded by the Technology Services and Development Department of Ontario Hydro to identify opportunities for drying, curing, non-metallic heating and heat recovery in Ontario industry.

It was intended that the investigation identify electrotechnologies being used elsewhere in promising applications where Canadian application was currently limited. It was also expected that promising applications would be identified which would require further research and development before market introduction. While the main criteria for selection or targeting of a particular application for technology transfer or further research was the undeniable benefit(s) which imply technical and economic feasibility to the industrial customer, other criteria, of varying importance were considered. These are:

- Replication Potential (ie, as a first approximation, the number of plant sites in Ontario within the same industry classification);
- Energy/Demand Reductions;
- Environmental Benefit;
- Trade Allies (ie, outside organizations, including industry associations and universities involved in research and development, with interest in promoting or co-sponsoring the development of a particular application or have work in progress which could benefit Ontario Hydro and its industrial customers);
- Industry Health (eg, particular interest in fast growth industries and industries of significant size capable of investing or compelled to invest in new technologies).

The targeted research projects, wherever possible, were to build on the expertise of the Process Applications Laboratory of Ontario Hydro's Research Division. Over the past 5 years, this group has gained a great deal of practical experience in product drying. They understand where, how and when to apply electrotechnologies to achieve the best results for the industrial customer. New opportunities to apply the existing capabilities and facilities of the Process

Application Group, in co-funded research and development projects, in collaboration with other universities or research institutes were to be sought.

The scope of the investigation was to identify promising applications for electromagnetic radiation technologies (ie, microwave, radio-frequency, infrared, ultraviolet, electron beam) and electrically-driven, vapour compression equipment (open and closed-cycle) in curing, drying, non-metallic heating and heat recovery processes.

### 1.2 Objective

To identify, analyze and report, through an extensive review of published overview documents, significant opportunities for electrotechnologies in drying, curing, non-metallic heating and heat recovery processes.

### 1.3 Method of Approach

The search for published material of relevance was undertaken on three fronts. The Electric Power Research Institute (EPRI) Guides and the Gas Research Institute (GRI) Published Research Report directory were reviewed to identify key, overview documents, prepared by these organizations on the industrial processes of direct interest to the study. Those reports not held by Caneta or Ontario Hydro were ordered by the Product Knowledge Centre, Technology Services and Development Department, Ontario Hydro.

Additional published material was identified through the Canadian Committee on Electrotechnologies (CCE), the International Union for Electro-Heat (UIE) and the Canadian Electrical Association (CEA) and obtained for indepth review and analysis. Energy use statistics and Standard Industrial Classification (SIC) data for industry were obtained from the Ontario Ministry of Energy and Statistics Canada. These statistics would be used to identify appropriate SIC codes for interesting electrotechnology applications. The same data also provided an indication of the importance of energy cost in a particular industrial segment, the size of the industry (value of shipments) and the number of establishments in Ontario.

A total of 82 research reports, technology transfer documents and technical articles were identified and are listed in Chapter 6, References. From these references, the key documents were identified following an initial review, and information of direct relevance to the particular process was documented. The information needed to assess the opportunity, for a particular application includes the following:

- Description of the application;
- How was the application currently done in industry?;
- What electrotechnology is used to perform the same task? What is the industrial application status of the electrotechnology?;
- What are the limitations of the electrotechnology compared to the current technology?;

- Are there unresolved problems or questions which need to be answered? What are the R & D needs?;
- Are there applications already in-place elsewhere? What are the technology transfer needs?;
- What is the potential for replication in Ontario (ie, number of similar establishments in Ontario suitable for the same application)?;
- Key references in the literature describing the application;
- Trade Allies for future collaboration.

Finally, individual, process-oriented reports on drying, curing, non-metallic heating and heat recovery were to be prepared which would present the full range of applications identified, the rationale for targeting of specific applications for future research or technology transfer efforts, and the R & D and technology transfer opportunities.

This report presents the opportunities for drying applications in Ontario industry using electromagnetic radiation, vapour compression and superheated-steam technologies.

## 2 DRYING APPLICATIONS

Drying in this report refers only to the removal of water from a solid or semi-solid material. While the most common solvent is water, the removal of organic solvents is often referred to as drying (eg, spray painting). These other solvent drying applications are not covered in this report. With the exception of ultraviolet and electron beam, each of the electromagnetic and heat pump technologies can be applied to drying applications in industry.

### 2.1 Energy Use in Drying

Total manufacturing energy use in the United States was estimated [26] to be 3400 terawatt-hours equivalent in 1985. Of this total, 2300 terawatt-hours equivalent were for process heating. Natural gas accounted for about 45% of this total or 1020 terawatt-hours. Natural gas consumption for baking, drying and curing operations [26] was equivalent to about 220 terawatt-hours used in process heating applications in manufacturing industries.

On the other hand, the **total** use of electricity in process heating [26] were estimated to be only 60 terawatt-hours or about 3% of the total. Of this, only 5.5 terawatt-hours were consumed in electric drying and curing applications. As a comparison, the electrical energy consumed by motors, in the manufacturing sector [26], was 508 terawatt-hours, or two orders of magnitude greater.

A study for Ontario Hydro in 1985 [1] estimated process heating energy consumption in Ontario to be 40 terawatt-hours. Process heating electricity use was estimated to be 0.75 terawatt-hours, or about 2% of the total. This compares favourably with the 3% estimated for the United States [26]. While data on electric drying energy use could not be found for Ontario, a similar penetration to that shown in the U.S. data is anticipated. It can therefore

be concluded that drying processes are predominantly fossil-fuel based and will likely continue to be so. The exceptions will be drying processes where electrotechnologies offer significant benefits to the industrial customer. While there are many industries with drying opportunities for electrotechnologies, the load impact will likely be minimal.

Recent data published by EPRI [26] estimated the electricity consumption of electrotechnologies in various industry categories. The industry category with the most drying applications is the Non-Metals Fabrication area. Radio-frequency heating and drying were estimated to account for about 2 billion kWh of electricity use; microwave heating and drying only 140 million kWh. In total, this electricity consumption represents only about 2% of the total electricity consumption in the Non-Metals Fabrication industry category in the United States. This data supports the earlier statement that the electrotechnologies investigated here are likely to have minimal load impact on Ontario Hydro in the future.

### 2.2 Reasons For and Methods of Drying

Drying is required in different industrial processes for various reasons, for example: to improve product handling; to provide for a product's required physical state or strength; to prevent rot of food products; to stabilize the size and shape of a product (eg, timber); to reduce the weight and hence the cost to transport a product; and, to improve the combustion efficiency for burning a product.

Drying of industrial products can be achieved by various methods, such as by mechanical means, absorption, thermal processes or dehumidification. The electrotechnologies discussed here either involve the thermal method or a combination of thermal and dehumidification. A total of 43 processes involving product drying were identified in the review of the technical literature. While not necessarily exhaustive, the processes summarized in the Drying Applications in Industry matrices in Appendix A cover all major industry segments. Each process is described and information provided where available, on benefits, limitations, R & D and technology transfer needs and replication potential in Ontario, for electrotechnology application.

### 2.3 Benefits of Electrotechnology Drying Processes

Microwaves are that frequency range of the electromagnetic spectrum between 300 and 300,000 MHz. They are used to dry electrically non-conducting materials (dielectrics) with polar molecules. The most common dielectric with polar molecules is water. Electromagnetic radiation in the radio-frequency range (13.56 MHz to 27.12 MHz) can also be used to heat dielectric materials. The radio-frequency field tends to induce vibration in the electrically - asymmetric polar molecules, dissipating electric energy and producing heat. The microwave and radio-frequency (RF) technologies, applied to drying processes, usually provide benefits such as reduced processing time, or increased throughput compared to the conventional drying technology. Product quality is normally said to be improved. RF drying has generally lower owning and operating costs than microwave [80]. While energy savings are not often

quantified, in general, savings will be greatest in applications where the product volume to surface area is large. Microwave equipment, combined with convective heating, has been shown to result in a significant reduction in electrical energy use compared to conventional convective drying equipment. An example of this was cited by Schmidt [82] where, in a pasta drying process, the replacement of the conventional convective equipment with a combination microwave/convective dryer resulted in a 40% overall reduction in electricity use, after accounting for microwave electrical energy consumption, due to significant reductions in conveyor and fan energy use. There may be many other industrial application areas where similar electricity conservation opportunities exist.

Infrared radiation is the wavelength range of the electromagnetic spectrum from about 1 to 400 microns. Materials such as textiles and paper, containing water, readily absorb energy in the infrared range within thousandths of a centimetre of the surface. Infrared energy is therefore ideal for certain drying applications. Electric infrared drying equipment is also claimed to provide increased product throughput, lower capital and operating costs and resulting cleaner product than conventional hot air drying methods. Electric infrared equipment often competes against gas-fired infrared which may put it at an operating cost disadvantage in areas where natural gas is available. However, electric infrared is claimed to have lower first cost, result in a cleaner product and better working conditions and produce higher output power densities than natural gas-fired infrared.

In addition to microwave, radio-frequency and infrared heating, two additional electrotechnologies were examined: electrically-driven vapour compression equipment and electric superheated-steam dryers (SSD). Heat pumps deliver more thermal energy than the amount of electrical energy they consume. They use compression energy to elevate the temperature of a working fluid. Closed-cycle heat pumps, such as dehumidification dryers, use such refrigerant as a working fluid, while open cycle heat pumps, such as mechanical vapour recompression units, use the process fluid, usually steam, as the working fluid. Both mechanical vapour recompression (MVR) and closed-cycle dehumidification dryers are classified as vapour compression equipment or heat pumps. The latter has been used extensively in Ontario for drying of hardwoods for furniture manufacturing. Energy savings can be significant compared to traditional heat-and-vent dryers and improved product quality is often claimed. MVR-equipped dryer kilns, while not yet fully developed, are claimed to offer even higher energy savings than dehumidification equipment. SSD promises higher drying rates than with conventional air-drying equipment. For example, in food drying, the absence of air (oxygen) is said to improve product quality. Even some wood products can be dried in an atmosphere of superheated-steam without product degradation. Veneer is one such example.

Additional technical information on drying electrotechnologies can be found in several references [17,21,22,23,26,27,44,47,82].

## 2.4 Limitations Of Electrotechnology Drying Processes

Microwave drying equipment has generally a higher capital cost than conventional drying equipment, an intermediate energy conversion efficiency, with overall efficiency dependent on the product's dielectric properties, its shape and size. RF equipment, while having a lower capital cost than microwave equipment, is better suited to applications where the product has a regular shape with large dimensions and with a high dielectric loss factor. Due to capital cost considerations, microwave equipment is restricted to relatively low applied power applications, normally less than 50 kW capacity.

Infrared equipment is best used in line-of-sight applications where the product, to be dried, is in layers or sheets, which are repetitive and simple in form and shape. Where drying applications call for a combination of forced-air and infrared equipment, gas-fired infrared will often be the choice simply because natural gas is already used in most forced-air drying equipment.

Vapour compression drying technologies require high plant utilization to justify high capital cost of equipment compared to more conventional heat-and-vent drying equipment. Contaminant carry-over from drying processes can cause problems with heat exchangers or the compressor in closed and open cycle vapour compression systems, respectively. Heat exchangers may corrode if the condensate is corrosive, whereas particulate in the suction steam can damage the steam compressor. Drying temperatures are also limited with current vapour compression technology. Super-heated steam dryers employing vapour recompression require the maintenance of an air-free atmosphere of steam which may present a significant challenge in some drying applications. Some products may be sensitive to higher temperatures associated with steam drying and suffer discoloration, degradation or fusion of particles.

## 2.5 Selection of Drying Applications For Future R & D and Technology Transfer

The information needed to properly assess the opportunity for various electrotechnology applications was presented in the introduction. The matrices in Appendix A contain information gathered during the review of the literature or contributed by the project team members. In many cases, the information needed to provide a balanced or thorough assessment of a particular drying application could not be found. In some cases, the project team would have liked more information on which to base the selection of targeted applications.

The most important criteria, for selecting promising drying applications, was seen as the undeniable customer benefits. These factors vary from one electrotechnology application to another but generally involve one or more of the following:

- reduced material waste;
- increased process capacity or throughput;
- compact, high power density, significant space savings;

- improved taste, odour or appearance in the case of food products;
- the ability to recycle an otherwise waste product;
- elimination of a full-time operator with the attendant labour cost reduction;
- reduced risk of fire.

Many of these customer benefits result in clear technical and economic benefits to the industrial customer, often with payback periods less than one year. In addition to the benefits, some applications also promise significant energy/demand reductions in drying processes or an environmental benefit. The latter is becoming more important in day-to-day corporate decision making.

Finally, a promising application's replication potential and the targeted industrial sector's health must be considered. Only where a significant number (or size) of industrial sites are known to exist, which meet the requirements of the application, can Ontario Hydro justify the resources to target R & D activities or encourage replication through technology transfer. In the consideration of industry health, applications in large Ontario-based industries or ones experiencing rapid growth are particularly attractive to target. Table 1, Appendix A, presents industry sector data which was used to evaluate an industry sector's attractiveness for targeting promising drying opportunities.

Only those Ontario industry sectors with identified drying opportunities for the electrotechnologies examined are presented in Table 1. The ranking in Table 1 is in descending value of shipments of goods (basis year 1986), with other measures of industry health shown, such as: value-added, growth in electricity used, number of establishments and intensity of value-added.

Figure 1 shows the ranking of these industries against different criteria. For example, Meat and Meat Products is the largest, by far, in value of Shipments of Goods, followed by Newsprint, Pharmaceutical and Medicine, Fruit and Vegetable, Plastic and Synthetic Resin to round out the top five. Other Dairy Products ranks sixth followed by Sawmill and Planing Mill, Pulp, Man-Made Fibre and Filament Yarns and in 10th place, Sugar and Chocolate Confections.

An even more important parameter to consider is value-added within specific industry sectors. This factor will generally provide a better indicator of a sector's level of manufacturing or processing as opposed to purchasing and passing through the cost of materials. As the value-added increases, an industry will more likely give serious consideration to adopting electrotechnology drying equipment, if there are undeniable benefits. The highest value-added industry in Figure 1 is Pharmaceutical and Medicine, followed by Newsprint, Meat and Meat Products, Fruit and Vegetable, and Plastic and Synthetic Resins. The industry sectors are the same as in Figure 1 except that the Pharmaceutical and Medicine sector changes positions with the Meat and Meat Products industry.

The number of establishments, within a particular industry sector, is also shown in Figure 1. This was used by the project team as a measure of the replication potential for a particular application. However, from a marketing standpoint, the less diverse an industry sector is, the more attractive it would be. Less diverse industry sectors are those with high value-added on a per establishment basis. Industry ranking from this standpoint has been calculated and added to Figure 1. The largest potential, by this measure, exists in targeting promising applications in the Newsprint industry, followed by the Pulp industry. These two industries have, by far, the highest value-added on a per establishment basis, of those industries with drying applications in Figure 1. A distant third is the Prepared Flour Mixes, Cereal Foods sector followed by the Man-Made Fibre and Filament Yarn industry in fourth. Number five, applying this measure, is the Gypsum Products industry.

The undeniable benefits, the replication potential and the industry health factors were all taken into account in the evaluation of the 43 drying applications and the selection of promising drying applications for future R & D and technology transfer activities. The next section briefly describes the rationale for the selection of the applications listed below; the specific R & D and technology transfer needed to encourage their replication in Ontario industry; and, organizations which may be appropriate for collaborative arrangements. The short list of opportunities is as follows:

- Moisture Profiling of Papers
- Drying of Textiles
- Drying of Wood Products
- Drying of Gypsum Wallboard;
- Drying of Pharmaceutical Granules
- Drying of Animal Waste
- Plastics Drying;
- Drying (dehydration) of Food Products.

**Figure 1 : Ranking of Industries with Drying Opportunities**

| Intensity* of Value Added | Number of Establishments | Intensity* of Value of Shipments |
|---|---|---|
| 1- *Newsprint* | 1- *Sawmill & Planing Mill* | 1- *Newsprint* |
| 2- *Pulp* | 2- *Meat & Meat Products* | 2- *Pulp* |
| 3- *Prepared Flour Mixes, Cereal Foods* | 3- *Other Dairy Products* | 3- *Prepared Flour Mixes, Cereal Foods* |
| 4- *Man-Made Fibre & Filament Yarn* | 4- *Fruit & Vegetable* | 4- *Man-Made Fibre & Filament Yarn* |
| 5- *Gypsum Products* | 5- *Pharmaceutical & Medicine* | 5- *Gypsum Products* |
| 6- *Pharmaceutical & Medicine* | 6- *Plastic & Synthetic Resin* | 6- *Plastic & Synthetic Resin* |
| 7- *Biscuit* | 7- *Contract Textile Dyeing & Finishing* | 7- *Pharmaceutical & Medicine* |
| 8- *Wafer Board* | 8- *Veneer & Plywood* | 8- *Wafer Board* |
| 9- *Frozen Fruit & Vegetable* | 9- *Man-Made Fibre & Filament Yarn* | 9- *Biscuit* |
| 10- *Plastic & Synthetic Resin* | 10- *Frozen Fruit & Vegetables* | 10- *Cereal Grain Flour* |

| Value of Shipments of Goods | Value Added | Growth in Electricity Use (%) |
|---|---|---|
| 1- *Meat & Meat Products* | 1- *Pharmaceutical & Medicine* | 1- *Wafer Board* |
| 2- *Newsprint* | 2- *Newsprint* | 2- *Contract Textile Dyeing & Finishing* |
| 3- *Pharmaceutical & Medicine* | 3- *Meat & Meat Products* | 3- *Meat & Meat Products* |
| 4- *Fruit & Vegetable* | 4- *Fruit & Vegetable* | 4- *Other Dairy Products* |
| 5- *Plastic & Synthetic Resin* | 5- *Plastic & Synthetic Resin* | 5- *Frozen Fruit & Vegetables* |
| 6- *Other Dairy Products* | 6- *Man-Made Fibre & Filament Yarn* | 6- *Wool Yarn & Woven Cloth* |
| 7- *Sawmill & Planing Mill* | 7- *Sawmill & Planing Mill* | 7- *Particle Board*** |
| 8- *Pulp* | 8- *Pulp* | 8- *Fruit & Vegetable* |
| 9- *Man-Made Fibre & Filament Yarn* | 9- *Prepared Flour Mixes, Cereal Foods* | 9- *Malt & Malt Flour* |
| 10- *Prepared Flour Mixes, Cereal Foods* | 10- *Other Dairy Products* | 10- *Veneer & Plywood*** |

* Intensity = (Value of Shipments) / (Number of Establishments)
** Value of Shipment Data Confidential

# 3 PROMISING DRYING APPLICATIONS

Applying the criteria described in detail in section 2, drying applications were selected from the 43 contained in Appendix A. Each of the applications targetted for technology transfer or further research and development are in industries in Ontario which rank in the top ten of one or more of the important criteria shown in Figure 1. Secondly, the application of electrotechnology to the specific process offers the industrial customer undeniable technical and economic benefits. In the case of research and development opportunities, while the same industry criteria were applied in the selection process, consideration was also given to the capabilities and facilities within the Process Application Group and the potential for collaboration with other research groups or agencies.

The following sections briefly describe each of these opportunities. For those applications involving further R&D, it is suggested that detailed project descriptions be prepared. An example of a project description is outlined in Appendix B.

## 3.1 Technology Transfer Opportunities

### 3.1.1 Moisture Profiling of Papers

The newsprint and printable papers industry in Ontario ranked 14th overall in value of shipments of goods of own manufacture in 1986. With only 9 newsprint establishments in Ontario, this sector is very attractive for targeting of promising applications. The profiling or cross-directional control of paper quality requires close control over, among other things, moisture distribution in the paper. Infrared profiling units, installed on paper machines at the final end of the water removal or drying process, offer a number of benefits, compared to gas-fired infrared systems. These have been identified as [17]: less fire risk, greater controllability, higher power density, reduced rejects of finished paper and increased throughput in situations where drying capacity is otherwise limited. Energy savings (steam) are achieved because the final product can have a higher moisture content reducing the amount of water which needs to be evaporated in the dryer section [63]. Better working conditions for operators are also claimed.

There have been a number of industrial applications in Europe, the United States and apparently in Canada, as well, which could be documented and disseminated to further promote the application within the Paper and Allied Products Industries. One research opportunity in this area might be to monitor installations in Ontario to determine the net change in overall plant electricity use as a result of implementing electric infrared moisture profiling. Research needs to be undertaken, as well, in the areas of system integration, optimization and improved control of the infrared component.

Potential collaborators with expertise within the paper industry are PAPRICAN in Montreal, Gordon Robb, Ottawa and the Lakehead University, where there is a group researching Pulp

and Paper processing. Impact Systems is an infrared supplier with application experience in this area.

### 3.1.2 Drying of Pharmaceutical Granules

Within the third ranking Chemical and Chemical Products Industries in Ontario, the Pharmaceutical and Medicine subsector ranks 16th overall in value of shipments of goods of own manufacture and ranks in the top five within the industries in Table 1. There are just under 70 establishments in this subsector in the province. In the production of pharmaceutical tablets there is a requirement to dry the granules before tablet formation. Traditional methods of drying have involved tray ovens with poor heat transfer and solids handling requirements. Fluidized bed dryers improved on these concerns but granule dust emission and dust explosion hazards and a need to clean down between product changeovers surfaced as new problems. The presence of highly potent active agents, in certain tablets, also necessitates providing adequate protection to both personnel and the immediate environment.

The application of microwave power for drying of pharmaceutical granules has been pursued for a number of years by ICI in collaboration with T. K. Fielder Ltd. [69]. Initial prototype dryers produced dried granules and tablets which were found to be as good, if not better than, conventionally dried granules. The microwave dried product was much less dusty than the material dried in a fluidized bed dryer. As with other microwave applications, the dielectric and thermal properties of the product being dried need to be taken into consideration. For example, wide variations in moisture and temperature can be a problem if the granules being dried have components with high loss factors.

This is a good example of an application involving a high value-added product to which relatively high cost microwave technology can be particularly advantageous. T.K. Fielder have an Ontario representative, H.G. Kalish Inc. who have indicated a willingness to collaborate on the transfer of this technology to Ontario industries. One approach would be to prepare case studies of actual installations which have been successful in the U.S. and Europe. A second approach would be to obtain a pilot-scale microwave drying unit from T.K. Fielder Ltd. to allow technology demonstrations for Ontario pharmaceutical industries.

### 3.1.3 Drying of Textiles

The Ontario Man-Made Fibre and Filament Yarn industry sector ranks 9th overall in Value of Shipments of Goods in Figure 1 and 6th overall in terms of value-added. The intensity of Value of Shipments of Goods (last column in Figure 1) ranks 4th behind Newsprint, Pulp and Prepared Flour Mixes and Cereal Foods industry sectors. This is an important industrial sector in Ontario which will require technological upgrading to survive in the face of foreign competition.

Infrared and radio frequency electrotechnologies are employed in the textile industry in Europe and Japan with some applications in the United States and Canada [17], [37], [68]. The

addition of an RF or infrared dryer to an existing gas-fired convection heater or steam-can dryer can free part of the dryer to increase throughput and can also save energy. Payback periods of one year are claimed [17]. Both infrared and radio-frequency dryers have the ability to dry, without overheating or damaging the textile sheet, bale or filament near the end of the drying process where moisture distribution is often uneven. With RF drying, there is no difference between outer and inner layer drying. Traditional methods tend to overdry the outer layer and underdry the inner layer. The energy consumption is claimed to be reduced by up to 66% in the area of the dryer where the moisture content is reduced from 20% to 5%. The drying time is reduced by approximately 33%. The degradation of colour and other textile characteristics due to overheating is claimed to be avoided.

Infrared and radio-frequency textile drying applications have been implemented elsewhere in the world. The opportunity exists to collaborate with the suppliers of radio-frequency and infrared equipment to produce case study material to raise the awareness of the Ontario industry. Possible radio-frequency equipment suppliers include: PSC Inc., Strayfield-Wiles, and Radio-Frequency Co. Ltd. [23]. Potential suppliers of infrared heating equipment include: Impact Systems and Can-Eng Sales Ltd. [47].

### 3.1.4 Drying of Animal Waste Prior to Disposal

While the Meat and Meat Products (excluding poultry) industries in Ontario are diverse with 200 establishments, this sector ranked 6th, overall, in 1986, in value of shipment of goods. Growth in 1988 was 22%, when comparing electricity consumption changes from 1987 to 1988. Waste meat product disposal is a common problem facing this industry and represents a significant cost in terms of transportation and disposal.

The animal waste, if dried, can be turned into a number of value-added products such as cattle food components, bone glue, oil and grease and bone ash for the china-industry [8]. Two installations in Belgium [8] and the Netherlands [68] show significant operating cost reductions (60%) when the conventional multiple effect evaporator is combined with an MVR system to concentrate the animal waste by removing the water. The payback period on the additional cost of the MVR equipment was under 1.5 years.

The Belgium installation was a central animal waste disposal facility where various establishments brought their waste to be concentrated and the resulting waste product was sold for use as described above in the production of further products. Atlas Copco, who supplied the compressor, in Europe, for this application, would be an appropriate ally for Ontario Hydro in examining the technical and economic feasibility of these applications in Ontario.

### 3.2 Research and Development Opportunities

#### 3.2.1 Drying of Wood Products

The Wood Products industry in Ontario has perhaps the second largest requirement for product drying next to the Paper and Allied Products industry. The production of lumber, for various end uses, starts with green wood containing up to 85% moisture. This must be reduced to less than 10% for practical uses. Softwoods require drying, in conventional steam kilns, for anywhere from 4 to 10 days; hardwoods anywhere from 10 to 30 days.

There are three industry segments of interest. The largest, Sawmills, Planing and Shingle Mills are diverse consisting of about 210 establishments in Ontario. The total value of shipments of goods of own manufacture ranked 35th in the Province in 1986. While scrap wood boilers are commonly used to raise steam for drying kilns in this sector, electric dehumidification dryers (heat pumps) have been widely and successfully employed, with significant energy savings. Estimates are that there are 100 dehumidification kilns in Ontario [79]. The same study suggested that retrofitting energy-efficient, variable-speed drives to the fans in these dehumidification kilns could result in energy savings of 30%. These savings are possible because design air flow is not required throughout the entire drying cycle.

A second segment of the wood industry where promising drying applications for wood products exist is the so-called Other Wood Industries. Within this group, in Ontario, are twelve particle board, five wafer board and an unknown number of fibre board plants. While not ranked in the top 50 industries, in Ontario, in terms of total value of shipments, these industry segments experienced average growth between 1987 and 1988 of about 6%. The five wafer board plants rank 8th, in terms of value of shipments per establishment, which makes them attractive for targeting of promising drying applications. Finally, the hardwood veneer and plywood industries, with 18 establishments in Ontario, is a third segment of this major industry group, with identified drying opportunities. Unfortunately, financial statistics are unavailable for the particle board or veneer and plywood sectors for reasons of confidentiality.

The drying of wood chips or wafers intended for use in fibre board or wafer board is an opportunity for an electric superheated-steam dryer. The conventional process uses direct contact flue-gas or indirectly heated air-drying. Neither of these conventional approaches permits economical energy recovery from vent exhaust [77]. While industrial-scale steam-drying applications (eg, drying of pulp, bark and hog fuel) have been operating for up to a decade in Sweden, attention has turned only recently to drying of particles for such finished products as particle or wafer boards. Based on pilot-scale experiments, the bending and tensile strength and the water absorption properties of the finished particle and wafer boards dried in a steam atmosphere were superior to those from air drying. One additional benefit was a reported 9% reduction in glue consumption in board manufacture. While no industrial-scale steam dryers for this application are known to be operating [77], further research appears warranted to encourage commercial development of superheated-steam dryers for this and similar applications in the Wood Industry.

There appears to be a number of drying opportunities for electrotechnologies in the Wood Products sector. Organizations investigating or developing applications in this sector include: Electricité de France, the University of Texas, Austin, and Modo Chemetics of Sweden. Dr. Mujumdar, Exergex Corporation, the author of a recent report for the CEA [77], appears to have considerable experience with drying technologies employed in this sector and could also collaborate with Ontario Hydro in this area. Finally, Forintek, in Ottawa, have interests, through their member companies, in pursuing applications with promise.

### 3.2.2 Plastics Drying

The Plastic and Synthetic Resin industry, in Ontario, consists of over 50 establishments with the value of shipments of goods ranking 21st overall. Considering only the industries with drying application in Table 1, Plastic and Synthetic resin industry ranks within the top six in all categories including, value-added, value of goods per establishment and number of establishments. Drying of polymers presents a unique challenge to conventional drying methods because of the heat-sensitive nature of the product. With polymers such as PVC and butyl rubber, for example, exposure to high temperatures (190 to 260°C) can result in poor molecular weight distributions and other unsatisfactory physical properties. By utilizing hybrid microwave or RF equipment, polymers can be dried at lower temperatures resulting in higher tensile strength, higher modulus of elasticity and improved appearance [17].

By combining microwave or RF equipment with a conventional hot-air drying system, a one-third reduction in total energy for drying of polymers is possible [17]. Retrofitting a microwave/RF unit to an existing polymer hot-air dryer is also claimed to increase production rates. Another benefit is the reduction of the organic solvents, which are removed from polymers in drying, rather than being released to the environment later, in an uncontrolled fashion.

EPRI, through the University of Texas (Austin), was funding development of an RF/hot air hybrid for plastic pellet drying; however, this program was discontinued and the prototype dryer returned to the owner, Ntronix (Dallas, TX). Discussions with Ntronix indicate a willingness to work together with Ontario Hydro (Process Applications Unit) towards developing a commercial unit for pellet drying. Further research is warranted to identify candidate polymers with suitable dielectric properties for drying and optimization of the hybrid, or combined RF and conventional hot air dryer, with respect to capacity matching, control and drying time. There should also be recommendations for product specifications with respect to initial moisture content, pellet size and shape to ensure compatibility with the RF drying equipment.

### 3.2.3 Drying of Gypsum Wallboard

The Gypsum products industry in Ontario manufactures wallboard and other related products at seven establishments. While the value of shipments of goods of own manufacture itself

does not rank high, the value-added per establishment ranked 5th in Ontario, based on 1986, Statistics Canada data, Table 1.

Gypsum wallboard is traditionally dried in direct-fired combustion, forced air ovens. The combustion air is typically taken from inside the plant which necessitates additional make-up air heating in winter and can result in uncomfortable conditions for employees. In addition, the combustion process itself produces water which needs to be eliminated along with the moisture in the wallboard. The temperature in the drying oven needs to be carefully controlled, particularly at the end of the oven, to avoid calcination of the gypsum in the wallboard, which leads to increased scrap.

Combining the conventional oven with a radio-frequency dryer at the dry end of the oven [78], shows promise of reducing scrap due to calcination from overheating. The experiments [78] demonstrated that the radio-frequency dryer was self-correcting, as the free-moisture was removed from the wallboard. The overheating, which often occurs with traditional ovens at this stage of the process, was not evident. Scrap reductions of 4% are predicted, which for certain energy costs and wallboard market-prices, can result in attractive pay-back periods for the wallboard produced.

The preliminary experiments have been conducted, in pilot scale only, at the University of Texas [78]. The next step involves planning, design, development, and implemention of the RF enhanced drying in a full-scale gypsum plant. Both Ontario and Quebec are large producers of gypsum wallboard and perhaps a co-operative research and development undertaking involving the Process Application Group, Ontario Hydro's Research Division, LTEE (Hydro Quebec) along with the University of Texas, Austin and an RF manufacturer such as PSC Inc. could result in an RF enhanced dryer and its associated benefits for Canadian gypsum wallboard producers.

### 3.2.4 Drying of Food Products

The canned fruit and vegetable industry in Ontario consists of approximately 80 establishments and ranked 20th in the province in value of shipments of goods in 1986. Growth, estimated by increased electrical energy consumption, was 10% in 1988.

Vegetables and fruits must be initially dried from 45% to 10-15% moisture content to ensure longer preservation while awaiting further processing. While drying by conventional means involves fuel-fired, hot-air convection processes, the combination of microwave or RF with a conventional drying system should result in reduced drying time, reduced hot-air requirements and energy savings.

Research and development is needed, however, to optimize microwave/convection and RF/convection systems to ensure that the required product quality and energy savings are achieved.

A variation of the above approach, for the same application, combines microwave and a vacuum chamber for dehydration of vegetables. The Japanese [69] have commercialized a 24-kW microwave/vacuum unit for dehydration of vegetables, in near vacuum conditions, to ensure long period preservation. The process is said to be faster and more efficient, without adverse effects to the product or loss of nutrients. Uniformity of heating inside the produce is said to reduce overheating associated with conventional hot air drying methods. However, the product specifications such as moisture content, thickness, and shape can impact on the success of this method. Improvements in the microwave/vacuum chamber drying process are required in the areas of treatment vacuum pressure, precise control of the microwave power, drying time and maintaining higher nutrient levels, if possible. There is an opportunity to collaborate with interested groups towards developing a hybrid technology that will bring about these improvements. Such groups would include: the EM&R food and beverage task forces; Food Technology centres (eg, Horticultural Research Centre); university researchers (eg, David Pei - University of Waterloo); and, equipment manufacturers (eg, R&J Engineering, Cober Electronics, Raytheon Corp.)

## 4 CONCLUSIONS

There is a very large number of potential electrotechnology drying applications within different industrial processes. A total of 43 drying applications were identified by the project team in an extensive review of published overview documents.

Nine drying opportunities were selected on the basis of their undeniable benefits to industrial customers, while at the same time taking into consideration the size, financial health and diversity of the particular industry sector in Ontario. This investigation made every effort to identify those electrotechnology drying applications which were most likely to be attractive to the most important industrial sectors in the province. Another consideration was that potential collaborators or co-funding agencies interested in Ontario Hydro plans, be identified. Wherever possible, research opportunities were selected to complement the facilities and capabilities of the Process Applications Unit of Ontario Hydro's Research Division.

This study identified the following technology transfer opportunities:

- moisture profiling of fine paper using high-intensity infrared heating;
- microwave/vacuum drying of pharmaceutical granules;
- drying of textiles with infrared or radio-frequency heating; and,
- drying of animal waste using mechanical vapour recompression (MVR) together with a conventional multiple effect evaporator.

The following opportunities for further research and development were identified:

- superheated-steam drying of particles used in manufacturing wafer and particle board;
- retrofitting variable speed fans for dehumidification wood-drying kilns;
- drying of polymer pellets using microwave or radio-frequency heating combined with hot air;
- drying of gypsum wallboard using radio-frequency heating combined with direct-fired, forced-air ovens; and,
- drying (or dehydration) of food products using an RF/microwave hybrid and microwave vacuum.

Other industry sectors which offer promise for improved electrotechnology in drying application are: the Pulp industry and the Prepared Flour Mixes, Cereal Foods industry sector. While

electrotechnologies have been proposed or even tried in these areas (eg, superheated-steam drying of pulp and microwave drying of cereals, insufficient evidence could be found, within the overview documents, to conclude that there were undeniable benefits to the industrial customer. However, these industrial sectors are attractive to target because they have relatively few establishments in Ontario and a high value of shipments or value-added on a per establishment basis.

## 5 RECOMMENDATIONS

1. Based on the identified opportunities, the following approaches are recommended:

   a) For applications involving technology transfer, some confirmation of the size of the opportunity should be performed perhaps through a brief market research survey. Based on this verification, information highlighting actual case studies could be prepared and made available to Regional customer energy staff to Ontario-based companies. Equipment suppliers, actual users and other collaborators could be approached to undertake this study.

   b) For R & D opportunities, project descriptions (objective, scope, rationale, level of funding, estimated completion, deliverables, collaborators, etc.) should be prepared and pursued for each application. An example of this type of study is outlined in Appendix B.

2. A technical demonstration using variable-speed drives for the fans of a dehumidification wood kiln should be undertaken to quantify the opportunity for significant electrical savings.

3. For those studies not directly relevant to Ontario Hydro's current corporate goals, unsolicited proposals or 'Request for Proposals' based on defined opportunities could be prepared with external collaborators for possible outside funding (eg, CEA, EPRI, Ministry of Energy - Enersearch Program, Department of Energy, Mines and Resources).

4. Efforts to locate Canadian-based collaborators (eg, university researchers, trade associations, equipment manufacturers) should be continued.

5. An investigation should be initiated to determine which industry groups are best able to afford investment in new electrotechnologies.

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## APPENDIX A

## DRYING APPLICATIONS IN INDUSTRY

| SIC CODE | Industry Sector | Value of Shipments of Goods ($'000) | Value-Added ($'000) | Growth in Electricity Use (%) | Number of Establishments | Intensity of Value-Added ($'000/establish.) |
|---|---|---|---|---|---|---|
| 1011 | Meat & Meat products | 2,689,505 | 590,828 | 22% | 201 | 2,939 |
| 2712 | Newsprint | 1,590,081 | 811,299 | -8% | 9 | 90,144 |
| 3741 | Pharmaceutical & Medecine | 1,376,210 | 988,744 | -8% | 67 | 14,757 |
| 1031 | Fruit & Vegetable | 1,281,529 | 574,801 | 4% | 79 | 7,276 |
| 3731 | Plastic & Synthetic Resin | 1,232,163 | 415,791 | -23% | 54 | 7,700 |
| 1049 | Other Dairy Products | 1,163,956 | 225,663 | 16% | 96 | 2,351 |
| 2512 | Sawmill & Planing Mill | 851,314 | 321,652 | -2% | 210 | 1,532 |
| 2711 | Pulp | 726,159 | 282,149 | -93% | 5 | 56,430 |
| 1811 | Man-Made Fibre & Filament Yarn | 675,854 | 360,703 | -1% | 16 | 22,544 |
| 1083 | Sugar & Chocolate Confections | 480,818 | 223,950 | 3% | 42 | 5,332 |
| 1052 | Prepared Flour Mixes, Cereal Foods | 466,468 | 277,919 | -3% | 10 | 27,792 |
| 1051 | Cereal Grain Flour | 360,032 | 63,535 | 14% | 20 | 3,177 |
| 1071 | Biscuit | 304,966 | 160,771 | 2% | 16 | 10,048 |
| 3593 | Gypsum Products | 262,598 | 155,555 | -4% | 7 | 22,222 |
| 1032 | Frozen Fruit & Vegetable | 217,442 | 105,852 | 10% | 13 | 8,142 |
| 1711 | Leather Tanneries | 128,136 | 30,595 | 0% | 17 | 1,800 |
| 2592 | Particle Board | 105,500 | 42,166 | 6% | 12 | 3,514 |
| 2593 | Wafer Board | 98,386 | 43,039 | 43% | 5 | 8,608 |
| 1092 | Dry Pasta Products | 87,055 | 38,657 | -3% | 11 | 3,514 |
| 1821 | Wool Yarn & Woven Cloth | 66,877 | 47,372 | 8% | 9 | 5,264 |
| 1992 | Contract Textile Dyeing & Finishing | 47,662 | 21,728 | 24% | 33 | 658 |
| 2521 | Veneer & Plywood | N.A | N.A | 0% | 18 | - |
| 1094 | Malt & Malt Flour | N.A | N.A | 3% | 4 | - |
| 1081 | Cane & Beet Sugar | N.A | N.A | -40% | 2 | - |

Table 1 : Health of Industrial Sectors with Drying Opportunities

## Table 2 : Summary of Drying Applications in Industry

**Food Industries (10)**

| | |
|---|---|
| 1- Food Freeze-Drying | (MW) |
| 2- Drying of Animal Waste prior to disposal | (MVR) |
| 3- Drying of Gelatine. | (HP) |
| 4- Drying of Fish | (HP) |
| 5- Dehydration of Food Products | (MW) |
| 6- Vacuum Drying of Vegetables | (MW) |
| 7- Drying of Fruits and Vegetables | (MW) |
| 8- Drying of Vegetables | (HP) |
| 9- Drying of French Fries | (RF) |
| 10- Drying of Whey Powder | (SSD) |
| 11- Drying of Cereals | (MW) |
| 12- Drying of Soy Sauce Cake (animal feed / fertilizer use) | (SSD) |
| 13- Drying of Pet Food, and Animal Feed | (RF) |
| 14- Post Baking of Cereals / Biscuits | (RF) |
| 15- Drying of Spent Beet Pulp for Cattle Food | (SSD) |
| 16- Bean Drying | (IR) |
| 17- Pasta Drying | (MW) |
| 18- Drying of Malts | (HP) |

**Primary Textile Industries (18) & Textile Products Industries (19)**

| | |
|---|---|
| 19- Drying of Man-Made Textile Fibres | (RF) |
| 20- Drying of Yarns | (RF) & (MW) |
| 21- Drying of Natural Textile Fibres | (RF) |
| 22- Textile Drying Processes | (RF) |
| 23- Drying of Textiles after Dyeing | (HP) |
| 24- Drying of Textiles prior to finish drying | (IR) |

**Wood Industries (25)**

| | |
|---|---|
| 25- Drying of Hardwoods | (RF) |
| 26- Drying of Timber | (HP) |
| 27- Drying of Lumber | (SSD) |
| 28- Drying of Veneer | (SSD) |
| 29- Drying of Wood Chips | (SSD) |

**Paper and Allied Prods. Industries (27)**

| | |
|---|---|
| 30- Moisture Profiling of Paper | (RF) |
| 31- Moisture Profiling of Paper | (IR) |

**Non-Metallic Mineral Prods. Inds. (35)**

| | |
|---|---|
| 32- Mold Drying | (MW) |
| 33- Ceramic Fibre Drying | (RF) |
| 34- Gypsum Wallboards | (RF) |
| 35- Drying of Fibreglass | (RF) |

**Chemical & Chemical Prods. Inds. (37)**

| | |
|---|---|
| 36- Plastics Drying | (RF) & (MW) |
| 37- Drying of Pharmaceutical Granules | (MW) |

**Miscellaneous Industries**

| | |
|---|---|
| 38- Drying of Tobacco | (HP) |
| 39- Drying of Polyurethane Foam | (RF) |
| 40- Drying of Leather | (RF) |
| 41- Electrical Equipment Parts Drying | (IR) |
| 42- Drying of Coal | (MW) |
| 43- Drying of Peat | (SSD) |

LEGEND :
- MW = Microwave
- RF = Radio Frequency
- IR = Infrared
- HP = Closed-cycle Heat Pump
- MVR = Mechanical Vapour Recompression
- SSD = Superheated Steam Drying

## Table 3 - Food Industries -

| Applications (SIC Code) | Food Freeze-Drying (10) | Food Industry (1011) | Food Industry (1011) |
|---|---|---|---|
| Description of application | Process removes ice from food products by sublimation, usually under vacuum | Drying of Animal Waste prior to disposal. | Drying of Gelatine. |
| How currently done in Industry ? | Sublimation heat provided by hot water electric resistance or I.R heating | A two effect evaporator (gas fired) boiler with finisher. | Dried in a continuous conveyor convection oven. |
| What Electrotechnology is used ? | Microwave | Open cycle heat pump (MVR). | Closed-cycle heat pump (and hx's). |
| Industrial application status | As of 1984 : One in the U.S<br>Many in Europe | Limited. Belgium, The Netherlands | Only in Japan. |
| Benefit(s) of the Electrotechnology | First, high quality product due to : irreversible changes (protein denaturation, enzyme browning) are minimized at the low process temperature; products are easily rehydrated because freeze-drying leaves solid skeleton intact; flavour, aroma and texture of products are retained after rehydration. Second, processing time reduced | Significant operating cost reduction compared to original (60%). Payback Period reported under 1.5 years. The original evaporator has been retained as a finisher. Waste products can be used to produce cattle food components, bone glue, oil and grease, bone ash for china industry | Significant reduction in steam consumption (from 3.2 to 5 tonne per hour). Capital costs are apparently similar to conventional dryer used in this application. Allows for low temperature drying. |
| Limitation(s) of the Electrotechnology | High equipment cost and low energy efficiency utilization due to : Electrical field strength in excess of 100V/cm is required to sublimate ice (it requires 80 times more energy than to temper food prods. from -20C to -2C) Ice is a poor absorber of MW power<br><br>Arcing problem (high electric field) | High capital cost. Must have source of steam for start-up. Preventative maintenance required. | High capital costs. More complex, requiring personnel training and preventative maintenance. Reliability and maintenance requirements unknown. |
| R&D Needs | R&D to determine how to improve efficiency of process, and avoid arcing problems damaging products | Establish potential in Ontario for central processing. Markets for resulting dried waste. | Establish potential in Ontario. |
| Technology Transfer | Prepare case studies to raise awareness in Ontario Industry. | Investigate applications in Europe, raise awareness in Ontario Meat/Poultry Industry. | Prepare case studies and disseminate in Ontario. |
| Potential in Ontario (Number of Establishments) | (1075) | (201) (Does not include poultry) | (201) (Gelatine Mfg. sites not known) |
| References | [17] [27] | [8] [68] | [68] |
| Allies | | Atlas Copco (West Germany) | Mayekawa Mfg. Co. (Japan)<br>Okhawara Mfg. (dryer) |

Table 3 - Food Industries (cont'd)-

| Applications (SIC Code) | Fish Processing (102) | Dehydration of Food Products (103) | Vacuum Drying of Vegetables (103) |
|---|---|---|---|
| Description of application | Drying of fish with dehumidification drier | Food products (i.e.:vegetables &fruits) must be dried from 45 % to 10-15 % moist content for longer preservation | Dehydration of vegetables by drying in near vacuum conditions to long periods preservation |
| How currently done in Industry ? | Drying outdoors or by fossil fuel fired boilers or furnace-heat and vent | Hot air convection process using conventional fuel-fired systems | Hot dry air and steam processes using conventional fuel-fired systems |
| What Electrotechnology is used ? | closed cycle heat pump | Microwave / Radio Frequency combined with conventional fuel-fired systems | Microwave associated with vacuum chamber or Radio Frequency |
| Industrial application status | Limited applications throughout Atlantic Canada | Development only during the 60's done by the U.S Dept. of Agriculture | Japan (Toshiba) commercializing of MW industrial equipment (24 kW @ 2450 MHz) |
| Benefit(s) of the Electrotechnology | Drying can be done year-round. Considerable energy savings as heat is only rejected from dryer when in excess of requirements. Average cost to dry fish (compared to oil) cut in half. Payback period of just over one year. Quality of fish better. May permit value pricing | If microwave/conventional systems are well designed, the benefits would be: Processing time reduced Plant space occupied is reduced Hot air requirements reduced Energy savings (unquantified) | Faster and more Efficient Without damage or substantial loss of nutrients Bulk and Weight of material are reduced Better quality due to : uniformity of heating inside bodies no overheating |
| Limitation(s) of the Electrotechnology | Drying time longer. Higher capital cost. Complexity requires operator training. | Operating costs (process needs a lot of power; relatively high elec. cost) SWEATING phenomenom due to heating profile in products decreases quality Low fruit & vegetable market volume and value may not justify high investments costs Restriction due to materials dielectric character and drying regime | Owning cost of MW equipment and vacuum chamber Less efficient for large volume mater'l and short operating times (with some overheating) Restriction due to materials dielectric character and drying regime Tight product specifications (input moisture content, thickness, shape...) |
| R&D Needs | Optimize drying schedules. | How to improve product quality, energy consumption, efficiency and uniformity of MW/convection systems for combined drying processes | Improvements required in areas of : treatment pressure, MW power control, operating time, design to achieve a higher nutrient product |
| Technology Transfer | Disseminate case study material to Ontario industry. | | |
| Potential in Ontario (Number of Establishments) | (19) | (92) | (92) |
| References | [11] | [17] [27] | [69] |
| Allies | Southwind Mfg. (Halifax) : fish dryers Uraken, Quebec. | | Toshiba (Japan) E.P.R.I (U.S) |

Table 3 - Food Industries (cont'd)-

| Applications (SIC Code) | Agricultural Applications (103) | Food Industry (1031) | Drying of French Fry (103) |
|---|---|---|---|
| Description of application | Drying of fruits and vegetables | Dehydration of fruits and vegetables for use in canned foods. | Drying of French Fries |
| How currently done in Industry ? | Ambient temperature storage for 3 or 4 days | Table type tunnel dryer at 120 C. | |
| What Electrotechnology is used ? | Microwave 'MIVAC' vacuum drying. | Closed-cycle heat pump. | Air Radio Frequency Assisted (ARFA) using high velocity air distribution. |
| Industrial application status | Some in U.S | One application in France. | Developed at the Electricity Council Research Centre (ECRC), UK |
| Benefit(s) of the Electrotechnology | Processing time reduced<br>Hygiene improved (due to disinfestation) | Substantial energy savings as only 20 percent of air is extracted the remainder re-circulated.<br>Specific energy consumption reduced from 0.85 kWh/kg to 0.30 kWh/kg.<br>Low drying temperature promotes better taste, flavour, less vitamin deterioration. | Studies performed at ECRC claim :<br>System can operate at much higher temp. (200 C compared to 90 C) due to properties of Radio Frequency dehydration, without overheating product.<br>The result is an extension of the constant rate period of drying with a subsequent decrease in drying time and dryer size |
| Limitation(s) of the Electrotechnology | High capital cost<br>Low efficiency and short utilization periods<br>Not generally economic<br>Protection against electromagnetic radiation. | Uncertainty about reliability.<br>Lack of application experience.<br>Higher capital cost.<br>More complex requiring operator training. | Studies performed at ECRC claim :<br>Improvement performance needs to be more than 500%, if not the system the system may not be economical |
| R&D Needs | Determine how microwave can assist/ enhance conventional drying methods. | Investigate current application and identify specific opportunities in Ontario canning industry. | Microwave power control<br>Optimization of operating time |
| Technology Transfer | 'MIVAC' equipment might be demonstrated in Ontario and case studies of U.S applications be presented | Develop case study of France installation for Ontario Industry. | Develop case study on VACARFA system applied in U.K. |
| Potential in Ontario (Number of Establishments) | (92) | (79) | (92) |
| References | [17] | [68] | [17] [61] [69] |
| Allies | | BEST Corp (Dryline)<br>Southwind (Halifax)<br>Uraken (Quebec) | Electricity Council, U.K.<br>(Capenhurst Research Centre) |

Table 3 - Food Industries (cont'd)-

| Applications (SIC Code) | Food Products (1049) | Agricultural Applications (1051) | Food products (1053) |
|---|---|---|---|
| Description of application | Drying of whey powder or skim milk powder. | Drying of grains | Drying of soy sauce cake (animal feed/ fertilizer use) |
| How currently done in Industry ? | Evaporation plus spray drying with natural gas. | Ambient temperature storage for 3 or 4 days | |
| What Electrotechnology is used ? | Open cycle heat pump (MVR) | Microwave 'MIVAC' vacuum drying. | Open cycle heat pump (MVR) |
| Industrial application status | Some in U.S | Some in U.S | Application in Japan since 1980 |
| Benefit(s) of the Electrotechnology | No oxidation reactions<br>Faster drying rates than with air<br>Energy efficient<br>Smaller equipment / less space<br>MVR has significantly lower energy costs than alternative. | Processing time reduced<br>Hygiene improved (due to disinfestation) | Drying in steam deodorizes soy sauce cake / more palatable as animal feed<br>Prod. sterilized at same time as drying<br>Enzyme deactivation occurs<br>Same plant can be used to roast rice bran<br>Product can be processed with low risk of thermal decomposition.<br>Space requirements less for MVR than multiple effect. |
| Limitation(s) of the Electrotechnology | Longer operating hours are required to make use of high capital cost equipment<br>Contaminants in exhaust from dryer<br>Compresser reliability.<br>MVR start-up requires source of steam.<br>Preventative maintenace required. | High capital cost<br>Low efficiency and short utilization periods<br>Not generally economic | High capital cost.<br>Preventative maintenance required.<br>Must be properly engineered to avoid noise related problems.<br>Must have source of steam for start-up. |
| R&D Needs | Improved heat transfer<br>Parameter investigations<br>Avoiding air entrainment | Improved dryer control. | Estimate potential for this & similar applications in Canada. |
| Technology Transfer | Case studies | 'MIVAC' equipment might be demonstrated in Ontario and case studies of U.S applications be presented | Case studies of Japanese applications to raise awareness in Ontario. |
| Potential in Ontario (Number of Establishments) | (96) | (20) | (178) |
| References | [12] | [17] | [75] [76] |
| Allies | Electricite de France<br>Wardrop Engineering | University of Guelph<br>Prairie Agricultural Machinery Inst.<br>Dantec Electronics, Waterloo. | Kikkoman Corporation, Japan<br>International Energy Agency, I.E.A. |

## Table 3 - Food Industries (cont'd)-

| Applications (SIC Code) | Drying of Pet Food (1053) | Post-Baking of Cereal / Biscuit (1071) | Food Industry (1081) |
|---|---|---|---|
| Description of application | Drying of Pet Food, and Feed Grains. | Product formation ,colouring and moisture removal are the 3 stages of post-baking of cereal/biscuit products | Drying of spent beet pulp for cattle food. |
| How currently done in Industry ? | Hot air convection process using conventional fuel-fired systems. | Hot air convection process using conventional fuel-fired systems | Rotating kiln using hot air heated by fossil fuel burner. |
| What Electrotechnology is used ? | Air Radio Frequency Assisted (ARFA) using high velocity air distribution. | Radio Frequency in addition to gas-fired oven. | Open cycle heat pump (MVR). |
| Industrial application status | Developed at the Electricity Council Research Centre (ECRC), UK | As of 1986 : One in Canada (4X50 kW)<br>Many in Europe and States | Limited. Japan, France . |
| Benefit(s) of the Electrotechnology | Studies performed at ECRC claim :<br>System can operate at much higher temp. (200 C compared to 90 C) due to properties of Radio Frequency dehydration<br>The result is an extension of the constant rate period of drying with a subsequent decrease in drying time and dryer size | Due to its moisture selectivity and penetrating characteristics, RF oven is used to provide more energy into the centre of the product. As a result :<br>* baking time is reduced<br>* speed increased in formulation and colouring stages to achieve an overall increase in production by as much as 50 %.<br>*less space required and less waste of raw materials<br>* automation and flexibilty improves quality control | Significant energy consumption reduction (750 kWh per tonne to 190 kWh per tonne). 4 year payback period. Better quality product due to absence of oxygen.<br>Condensate at over 100 C is useful in plant operation.<br>Less, bitter, softer, fluffier, more digestible.<br>Elimination of fire hazard.<br>Product can be processed with low risk of thermal decomposition. |
| Limitation(s) of the Electrotechnology | Studies performed at ECRC claim :<br>Improvement performance needs to be more than 500%, if not the system may not be economical | Difficulties to achieve good quality because RF has tendency to dry instead of baking<br>Relative high costs compared to gas fired ovens<br>Appearance, texture, flavour, aroma are inferior<br>Difficulty removing moisture where product to product moisture varies | Carryover of contaminants from superheated dryer sections to compressor.<br>Higher capital cost.<br>Preventative maintenance required.<br>Source of steam required for start-up. |
| R&D Needs | Radio Frequency power control<br>Optimization of operating time | | Identify other products which could be dried in similar process. |
| Technology Transfer | Develop case studies for disemination to Ontario Industry. | Raise awareness of Canadian industries | Develop case study on japanese and french installations. |
| Potential in Ontario (Number of Establishments) | (178) | (16) | (2) |
| References | [17] [61] [69] | [17] [37] | [68] |
| Allies | Vince Torres, U. of Texas.<br>Dantec Electronics, Waterloo. | Electricity Council, U.K.<br>(Capenhurst Research Centre)<br>Biscuit and Cookie Mfg. Association. | Heat Pump Technology Centre, Japan<br>International Energy Agency, I.E.A. |

## Table 3 - Food Industries (cont'd)-

| Applications (SIC Code) | Bean Drying (1083) | Pasta Drying (1092) | Food Industry (1094) |
|---|---|---|---|
| Description of application | Vibrating wedge-wire conveyor carries cocoa beans under a battery of IR generators. | After forming, pasta contains 30 % moisture and must be dried to about 12% | Drying of Malts. |
| How currently done in Industry ? | Hot air or gas-fired IR? | Hot air convection process using conventional fuel-fired systems | Upper deck, lower deck kiln with gas fired burners. |
| What Electrotechnology is used ? | Infrared Radiation | Microwave combined with conventional hot air fuel-fired systems | Closed-cycle heat pump. |
| Industrial application status | European company increased processing profits by 1% using gas-fired IR. | As of 1986,150 kW installed in the Canadian noodle and pasta industries. | Limited. Demos in U.K., France. |
| Benefit(s) of the Electrotechnology | Demonstrated with gas-fired IR :<br>Increased throughput.<br>Lower Mould & Bacteria counts.<br><br>Potentially with electric IR :<br>Cleaner product<br>Better working conditions | Process. time reduced from 8 to 1.5 hrs<br>Plant space occupied is reduced (length of dryers are often divided by 2 or 3)<br>Less clean-up time<br>Energy savings up to 20 %<br>Better hygiene<br>Hot air requirements reduced by 80 %<br>Product is crustless, enabling very fast cooking of pasta | Four units provide flexibility of control over drying process. Exhaust air is cooled to 15 C which is ideal for germination bins. About 60% energy cost saving including fuel oil savings in germination bin heating. |
| Limitation(s) of the Electrotechnology | Competition from gas-fired Infrared.<br>Shock sensitivity of some emitters.<br>Best suited to layers or sheets of material. | First cost<br>Conservative attitude of Industry (ind. avoid the uncertainties about reliability and long-term performance of MW drier components) | Possible heat exchanger fouling.<br>Uncertainty regarding reliability.<br>High capital cost.<br>More complex system requiring operator training. |
| R&D Needs | Evaluate relative position of electric IR. | R&D to quantify the improved hygiene and quality of products | Investigate success of off-shore installations, hold discussions with major malt producers in Ontario. |
| Technology Transfer | | Prepare case studies for disemination to Ontario Industry. | Prepare case study of U.K and France installations. |
| Potential in Ontario (Number of Establishments) | (42) | (11) | (4) (a total of eight large malting operations in Canada) |
| References | [17] | [17] [27] [37] | [14] [68] |
| Allies | Equipment suppliers. | | Equipment suppliers.<br>BEST Corp. |

## Table 4 - Primary Textile Industries & Textile Products Industries -

| Applications (SIC Code) | Drying of Man-Made Textile Fibres (1811) | Drying of Yarns (1821) | Drying of Natural Textile Fibres (1911) |
|---|---|---|---|
| Description of application | After being dyed and fixed, textile fibres are spun dried to reduce content moisture of 50-70% to 30-40% | Wool and wool mixture yarns have to be dried after being felted using a hot water mechanical process | After being dyed and fixed, textile fibres are spun dried to reduce content moisture of 50-70% to 30-40% |
| How currently done in Industry ? | Cabinet dryer (hot air circ.)<br>Some are combined with vacuum vessel | Batch oven hot air convection dryer using conventional fuel-fired systems | Cabinet dryer (hot air circ.)<br>Some are combined with vacuum vessel |
| What Electrotechnology is used ? | Radio-Frequency | Microwave or Radio Frequency | Radio-Frequency |
| Industrial application status | European and Japanese | Over 250 worldwide | European and Japanese |
| Benefit(s) of the Electrotechnology | Drying time reduced (33%)<br>Hot air requirements reduced<br>Energy savings up to 2/3<br>Better quality ( uniform dewatering)<br>More precise control of process<br>Flexibility with varied textiles<br>Lack of dye migration<br>Less heat damage<br>Capital cost equivalent to conventional | Processing time reduced<br>Better quality showing lower hairiness and higher strength than conventionally dried yarns. As a result, volume and thermal insulation properties of yarns improve<br>Exp. showed a 50% overall efficiency payback time (in Europe for different MW equipment) is between 2 and 3 years | Drying time reduced (33%)<br>Hot air requirements reduced<br>Energy savings up to 2/3<br>Better quality ( uniform dewatering)<br>More precise control of process<br>Flexibility with varied textiles<br>Lack of dye migration<br>Less heat damage<br>Capital cost equivalent to conventional |
| Limitation(s) of the Electrotechnology | Perceived as new untried technology by conservative industry.<br>Industry is mature and no longer expanding - lacks of funds for new capital acquisition<br>Some damaged reported due to arcing. | RF has lower owning and operating costs than microwave<br>Industry is mature and no longer expanding - lack of funds for new capital acquisition | Perceived as new untried technology by conservative industry.<br>Industry is mature and no longer expanding - lacks of funds for new capital acquisition |
| R&D Needs | | | |
| Technology Transfer | Produce a series of case studies pointing out benefits of textile applications of radio frequency | Increase awareness of successful applications in Ontario by way of case studies | Produce a series of case studies pointing out benefits of textile applications of radio frequency |
| Potential in Ontario (Number of Establishments) | (16) | (9) | (14) |
| References | [68] [37] | [17] [68] [37] | [68] [37] |
| Allies | Fibre Research Institute, Netherlands<br>Auburn University.<br>E.P.R.I. | Chuck Carr, Georgia Tech.<br>Auburn University.<br>E.P.R.I. | Fibre Research Institute, Netherlands<br>Auburn University.<br>E.P.R.I. |

Table 4 - Primary Textile Industries & Textile Products Industries (cont'd) -

| Applications (SIC Code) | Textile Drying Processes (1992) | Textile (1992) | Textile Drying (1992) |
|---|---|---|---|
| Description of application | After being spun dried, remaining moist. content of textiles needs to be reduced to between 10-20% dry weight base | Drying of textiles after dyeing. | Drying of textiles using Infrared radiation prior to finish drying |
| How currently done in Industry ? | Hot air convection process using conventional fuel-fired systems | Dried in heat and vent drying chambers by steam hx's . | Heavy fuel-fired superheated steam and gas-fired convection heaters |
| What Electrotechnology is used ? | Continuous Radio-Frequency dryer (conveyor belt) | Closed-cycle heat pump. | Infrared combined with convection heaters or steam cans |
| Industrial application status | Many European and Japanese Applications<br>As for 1986, 3 systems in CANADA | Limited. | Applied successfully in Canada, U.S., and Europe |
| Benefit(s) of the Electrotechnology | Main advantages are :<br>Homogeneite of the heating process<br>Moderate power density<br>No thermal & mechanical stresses due to absence of any dry layer at the surface<br><br>Results in :<br>Better tensile strength of the thread<br>Reduction of waste<br>Very important gain in maintenace (estimated up to 30%), cleaning almost unnecessary | Drying time has been reduced, processing of products can be done in significantly shorter period (1 day rather than up to 3 days).<br>Under 2 year payback in U.K. example.<br>No need for full-time operator, as before. | Much more space efficient<br>Frees part of dryer to increase throughput<br>saves energy<br>One year payback realized |
| Limitation(s) of the Electrotechnology | Some types of white fibre tend to turn yellow<br>Damage by arcing due to concentration of conductive materials (eg, salt sol.) in the fabric<br>Not well adapted to flat textile webs<br>Industry is mature and no longer expanding - lacks of funds for new capital acquisition | Contaminants carrying over from drying process may plug heat pump components requiring frequent cleaning.<br>High capital cost.<br>Limited operating experience in industry.<br>More complexity for operator. | Often requires on-site or laboratory testing of products and optimization of available equipment<br>Shock sensitivity of some emitters. |
| R&D Needs | Improvement in the design of electrode arrangement, voltage and frequency (to avoid arcing) and control systems to give optimum performance | | To verify and quantify claimed safety, energy consumption, and control advantages |
| Technology Transfer | Case studies of successful european and japanese applications | Case study preparation and dissemination in Ontario Industry. | Provide information on correct application and design of electric Infrared equipment |
| Potential in Ontario (Number of Establishments) | (33) | (33) | (33) |
| References | [17] [27] [61] [68] [69] | [68] | [17] [68] |
| Allies | Auburn University.<br>E.P.R.I. | Auburn University.<br>E.P.R.I. | Chuck Carr, Georgia Tech.<br>Auburn University.<br>E.P.R.I. |

## Table 5 - Wood Industries -

| Applications (SIC Code) | Seasoning of Wood (251) | Wood Products (251) | Wood Products (251) |
|---|---|---|---|
| Description of application | Drying of hardwoods with RF vacuum system | Drying of Hardwood timber. | Drying of lumber |
| How currently done in Industry ? | Hot air convection process using conventional fuel-fired systems | Heat & vent kilns with steam coil supp. from fossil fuel or scrap wood boilers. | Heat and Vent Kilns and Closed-cycle heat pump |
| What Electrotechnology is used ? | Radio-Frequency combined with a vacuum equipment | Closed-cycle heat pump. | Superheated Steam dryer |
| Industrial application status | As of 1986 : None in Canada<br>Many in the U.S and Europe | Many. | Commercial installations in Germany and Sweden. |
| Benefit(s) of the Electrotechnology | Better quality : even temp. profile and 30 % less shrinkage [27]<br>Processing time reduced<br>Plant space occupied is reduced<br>Less maintenance | Drying energy performance factor significantly improved (from 2 kWh/kg water to .86 kWh/kg water).<br>Heat pump dehumidifies the air before heating it and sending to drying process. Lower temperature drying is possible, improving quality of product. | Energy efficient<br>Significant reduction in drying time from 5 to 10 days to 30 hours or less<br>Capital and operating cots can be lower than in air<br>More consistent quality |
| Limitation(s) of the Electrotechnology | Degradation of RF dried wood [69]<br>High capital cost of RF equipment | Heat pump must be located outside kiln to avoid corrosion associated with acidity of the condersate.<br>Steam is still required to relieve "stress" in the wood at end of drying time. | Economics vary from application to application<br>Extractives and preservatives may become dissolved in steam<br>Contaminants in steam may damage compressor<br>Air may get entrained |
| R&D Needs | Investigation of a satisfactory trade-off between drying time and product quality | Develop dehumification unit capable of drying temp. up to 105 C for softwoods.<br>Develop MVR unit to operate in air free environment producing superheated steam | Overcoming problems due to air entrainments. Contaminants may damage compres.<br>Determine importance of various parameters |
| Technology Transfer | | | Case studies of German and Swedish installations for dissemination in Ont.<br>Not necessarily same wood materials. |
| Potential in Ontario (Number of Establishments) | (210) | (210) | (210) |
| References | [17] [19] [27] [69] | [34] [42] | [74] [76] |
| Allies | Peranitty, Finland.<br>E.P.R.I<br>Forintek | Forintek | U.S. Dept. of Agriculture<br>German Lumber Industry.<br>Forintek |

Table 5 - Wood Industries (cont'd)

| Applications (SIC Code) | Wood Products (2521) | Wood Products (2593) |
|---|---|---|
| Description of application | Drying of Veneer | Drying of wood chips for fibreboard or waferboard. |
| How currently done in Industry ? | Continuous rather than batch drying process | Heat and Vent or simply not used or used wet |
| What Electrotechnology is used ? | Superheated Steam Drying with MVR. | Superheated Steam Drying |
| Industrial application status | Not known | Installations in Sweden |
| Benefit(s) of the Electrotechnology | Veneer can be dryed in an atmosphere of entirely superheated water vapour. The vent exhaust has relatively constant characteristics-ideal for MVR. Very significant energy savings compared with conventional drying means | Large number of potential applications drying other waste products<br>Faster drying times<br>Energy efficient<br>Odour and particulate emissions reduced |
| Limitation(s) of the Electrotechnology | Difficulty associated with making kiln an air free atmosphere of steam (super heated)<br>Carry over of contaminants<br>May be necessary to clean up exhaust steam before compression. | Product degradation due to discolouration due to high temperatures.<br>Corrosive vapours may require expensive dryer materials. |
| R&D Needs | Is concept of air free atmosphere of steam in drying kiln feasible ?<br>What would be the performance index for such a system using MVR ? | Determine importance of various drying parameters. Air and contaminant entrainment in compressor suction .<br>Impact of steam condensate |
| Technology Transfer | | Case studies of succesful applications<br>Identification of other waste products |
| Potential in Ontario (Number of Establishments) | (18) | (5) |
| References | [34] | [71] |
| Allies | Vince Torres, U. of Texas<br>Gas Research Institute, G.R.I.<br>Forintek. | Electricite de France, Modo Chemetics<br>Dr. Mujumdar, McGill.<br>Forintek. |

## Table 6 - Paper & Allied Products Industries -

| Applications (SIC Code) | Moisture Profiling of Paper (2712) | Moisture Profiling of Paper (2712) |
|---|---|---|
| Description of application | Profile moisture content of a paper web | Profile moisture content of a paper web |
| How currently done in Industry ? | Conventional fuel-fired systems and Conventional Radio Frequency equipment | Fuel-fired Infrared / Convection<br>Fuel-fired steam cylinders |
| What Electrotechnology is used ? | "automated impedance matching network" Radio Frequency with moist hot air | Short-Wavelength Infrared or Infrared combined with resistance |
| Industrial application status | Developed in France (EDF) and starting to commercialize a 240 kW RF system | Europe,US,Canada / Average size:500 kW (only 35 % of this necessary?) |
| Benefit(s) of the Electrotechnology | Standard generators<br>Direct measurement of RF power<br>Ease of tuning<br>Given a matching box with wide tuning range, a RF system could be flexible enough to permit heating of different products with the same optimal efficiency | Relative to fuel-fired Infrared :<br>Reduced fire risk<br>Greater control (well-suited to computer-based control)<br>Higher power density (4kW/m2 vs 1kW/m2)<br>Energy savings due to selective use and high penetration<br>Improved product quality<br>Cutting equipment lasts longer<br>Improved raw material utilization and throughput<br>Better working conditions |
| Limitation(s) of the Electrotechnology | Higher capital cost than standard RF equipment<br>Reliability of the vacuum capacitors in matching network unknown. | Competition from gas-fired Infrared<br>Shock sensitivity of some emitters. |
| R&D Needs | Optimizating product cost/performance and reliability<br>Gluing applications to be investigated | System integration, optimization and improved controls.<br>Predictive modelling of processes.<br>Combining with microwave power |
| Technology Transfer | Document successful installations. | Document the most successful applications |
| Potential in Ontario (Number of Establishments) | (9) | Significant in Paper Mills (9) |
| References | [69] | [17] [68] |
| Allies | PAPRICAN, LAKEHEAD U.<br>Gordon Robb; Sairem, France<br>E.P.R.I., C.E.A. | PAPRICAN, LAKEHEAD U.<br>Gordon Robb; Impact systems.<br>Rolland Inc., Quebec |

## Table 7 - Non-Metallic Mineral Products Industries -

| Applications (SIC Code) | Mold Drying (359) | Ceramic Fibre Drying (359) | Gypsum Wallboards (3593) |
|---|---|---|---|
| Description of application | The mold (ceramic industries) must be dried to remove water absorbed from first casting in order to be reused | Drying of ceramic fibre board products (dewatering without affecting the surrounding ceramic fibre) | Drying of Gypsum Board |
| How currently done in Industry ? | Hot air convection process using conventional fuel-fired systems | Hot air convection process using conventional fuel-fired systems | Hot air convection process using conventional fuel-fired systems |
| What Electrotechnology is used ? | Microwave | Radio-Frequency | Radio-Frequency combined with convection dryer. |
| Industrial application status | Unknown | As of 1986 : None in Canada<br>Used by 3 large U.S manufacturers | Unknown. Under investigation by E.P.R.I |
| Benefit(s) of the Electrotechnology | Processing time reduced (from several hours to half hour)<br>Quality improved<br>Energy savings with better production (12 uses of the mold during 24 hour period instead of one use by conventio nal means)<br>Less maintenance : now allows process to be partially automated | Increased drying rates<br>Ability of RF to heat water without affecting the surrounding ceramic fibre<br>Less manufacturing<br>Better control of process | Internal heating is self correcting and avoids calcination.<br>Significant reduction in wallboard scrappage.<br>May increase production rate. |
| Limitation(s) of the Electrotechnology | First Cost | | Higher first cost. |
| R&D Needs | Determine capacity match and cost optimization for specific applications | | Need knowledge of dielectric and thermal properties of gypsum board for prediction modeling / optimization purposes. Identify operating strategy. |
| Technology Transfer | | Increase awareness of U.S applications in Ontario by way of case studies. | |
| Potential in Ontario (Number of Establishments) | (95) | (95) | (7) |
| References | [17] | [17] | [78] |
| Allies | McMaster U.; U. of Toronto<br>Cober Electronics. | McMaster U.; U. of Toronto | P. Schmidt, U. of Texas<br>B. Krieger, Cober Electronics<br>L.T.E.E, Hydro Quebec. |

Table 7 - Non-Metallic Mineral Products Industries (cont'd) -

| Applications (SIC Code) | Drying of Fibreglass (3562) |
|---|---|
| Description of application | Drying of fibreglass at primary stage : on bobbins, rovings packages, as mats & coated strands & continuous strands |
| How currently done in Industry ? | Hot air convection process using conventional gas-fired systems |
| What Electrotechnology is used ? | Radio Frequency flat batch oven conveyors |
| Industrial application status | 4 main U.S fibreglass producers are currently using RF (from 30kW to 600kW) |
| Benefit(s) of the Electrotechnology | Faster process : from 24 hrs to 1 hr<br>Uniform heating avoids overheating thus provides better quality product<br>Less space requirement (1/5)<br>Automation reduces labour costs and maintenance (RF is a cleaner system) |
| Limitation(s) of the Electrotechnology | Higher first cost.<br>Protection against electromagnetic radiation. |
| R&D Needs | |
| Technology Transfer | Case studies of successful U.S. applications |
| Potential in Ontario (Number of Establishments) | (74) |
| References | Personal communication |
| Allies | J. Zimmerly, PSC Inc, U.S.<br>Auburn University.<br>Krantz. |

Table 8 - Chemical & Chemical Products Industries -

| Applications (SIC Code) | Plastics Drying (373) | Drying of Pharmaceutical Granules (3741) |
|---|---|---|
| Description of application | Drying polymers such as PVC, butyl rubber, polyisobutylene... and to some extent other plastics products | Highly active pharmaceutical granules must be dried during granulation process |
| How currently done in Industry ? | Hot air convection process using conventional fuel-fired systems | Tray ovens and mainly fluidised bed dryer (convection/conduction) |
| What Electrotechnology is used ? | Microwave/Radio Frequency with hot air conventional fuel-fired systems | Batch vacuum Microwave dryer |
| Industrial application status | Unknown | Developped at Imperial Chemical Ind. (U.K) with T.K Fielder Ltd. collabor. |
| Benefit(s) of the Electrotechnology | Quality improved :<br>broader molecular weight distribution, higher tensile strength, higher modulus of elasticity, improved appearance<br>Pollution is reduced :<br>volatile organic solvents are removed from essentially non polar synthetic polymers to a level of less than 1 ppm<br>Others benefits are :<br>Less maintenance<br>Energy savings since small amount of energy is required with these electro. | High efficiency<br>Better productivity<br>Product quality improved :<br>less dusty, even moisture content and temperature levelling effect across the bed of granules<br>Space and Labour savings<br>Improved hygiene of pharma. product<br>Lower temperature of drying avoids destructive overheating |
| Limitation(s) of the Electrotechnology | First cost of MW equipment may be high if MW is not sized adequately with the conventional system<br>For both dielectric technologies :<br>Restriction due to materials dielectric character and drying regime<br>Tight product specifications (input moisture content, thickness, shape...) | More expensive than convent'l. systems<br>Safety considerations :<br>* should limit operator exposure to microwave radiation<br>* risks of fire & explosion of highly active products caused by arcing problems |
| R&D Needs | Optimization of RF/Microwave/Hot Air combined system :<br>cost, time, capacity matching, control of process. | Reliability and Arcing problems are areas of improvements for succesful applications in pharmaceutical field |
| Technology Transfer | | |
| Potential in Ontario (Number of Establishments) | (54) | (67) |
| References | [17] [27] | [69] |
| Allies | Vince Torres, U. of Texas<br>Wendall Goodman, Ntronix<br>Plastics Institute, E.P.R.I | T.K. Fielder (U.K) |

## Table 9 - Miscellaneous Industries -

| Applications (SIC Code) | Tobacco Prods. | Plastic Prods. Inds. | Leather & Allied Prods. |
|---|---|---|---|
| | Tobacco Industry (121) | Drying of Polyurethane Foam (1611) | Drying of Leather (1711) |
| Description of application | Drying of Tobacco by dehumidification. | Drying of Polyurethane Foam | Vacuum drying of leather is appropriate to preserve its physical and aesthetic properties |
| How currently done in Industry ? | Hot air generated by direct burning of fossil fuel with no heat recovery. | Hot air convection process using conventional steam-fired systems | Conventional vacuum dryers, heated air using fuel-fired systems |
| What Electrotechnology is used ? | Closed-cycle heat pump. | Radio Frequency batch oven conveyors | Continuous vacuum Radio Frequency tunnel oven |
| Industrial application status | Limited<br>(Significant number in Spain). | Some in U.S. | Europe (Italian company commercializes RF dryers in range 30-150 kW RF power) |
| Benefit(s) of the Electrotechnology | Significant energy savings (50%)<br>Tobacco has better quality and aroma because no longer contaminated with direct contact with fossil fuel fumes.<br>More uniform drying than before.<br>Payback of under 3 years reported. | Energy savings payback in 2 years<br>Uniform heating avoids overheating thus provides better quality product<br>Less space required<br>Faster | High efficiency<br>Even moisture profile<br>Flexibility of equipment<br>Low drying temperature :40 - 70 C<br>Better Control of Process (separate regulation of both heating & cooling)<br>Better quality product due to :<br>internal drying (inside generated heat)<br>flat skin with open pores<br>better feel<br>thermal fixation of the grain side of the skin is improved |
| Limitation(s) of the Electrotechnology | High capital costs.<br>More complex system requiring operator training.<br>Reliability and maintenance. | Protection against electromagnetic radiation. | Protection against electromagnetic radiation. |
| R&D Needs | | Radio Frequency power control.<br>Optimization of drying schedule. | Radio Frequency power control.<br>Optimization of drying schedule. |
| Technology Transfer | Case studies of successful applications to raise Ontario industry awareness. | Case studies of successful U.S. applications | Case studies of successful european applications |
| Potential in Ontario (Number of Establishments) | (7) | (48) | (15) |
| References | [68] | Personal communication | [68] |
| Allies | Uraken.<br>Dryline. | J. Zimmerly, PSC Inc, U.S. | |

## Table 9 - Miscellaneous Industries (cont'd) -

Electrical & Electronic Prods  Refined Petroleum & Coal

| Applications (SIC Code) | Electrical Equipment Parts Drying (337) | Drying of Coal (369) | Drying of Peat (?) |
|---|---|---|---|
| Description of application | Rebuilt components are dried (after steam cleaning), painted & dried again using IR ovens. | Drying of coal | Drying of Peat. |
| How currently done in Industry ? | Air dry or convection ovens | | Not currently done. Reduce moisture content for burning and transportation |
| What Electrotechnology is used ? | Short wavelength electric IR ovens. | Microwave in rotary kiln | Open cycle heat pump (MVR) |
| Industrial application status | In use - U.S. | Investigated at the MW Applications Research Centre (MARC), Bradhurst, AUS. | Limited. Sweden |
| Benefit(s) of the Electrotechnology | Space efficient<br>Fast<br>Allowed centralization of operations | Studies performed at MARC claim : 83 % efficiency with a 5kW Microwave Generator | Dried Peat briquettes burn at higher efficiency. Transportation costs are significantly lower. Peat briquettes now able to compete with coal as fuel for district heating plant. 25% of energy needed for conventional drying.<br>Space requirements can be minimized compared to conventional dryers. |
| Limitation(s) of the Electrotechnology | Competition from gas-fired infrared. | Economic (?) | Peat contaminant carry over to steam compressor.<br>Must have source of steam for start-up.<br>High capital cost.<br>Preventative maintenance required. |
| R&D Needs | Identify and quantify differences between electric and fuel-fired Infrared systems | Partial predrying warrants further investigation with industrial partner for a large-scale study | To investigate whether opportunities exist for this technology for producing fuel for cogeneration plants or even barbeque application |
| Technology Transfer | Case studies of electric infrared applications for Ontario Industry. | Awareness of MARC's activities in mineral field | Preparation of case studies to raise awareness on Ontario Industry. |
| Potential in Ontario (Number of Establishments) | Limited as installed fuel-fired Infra Red systems not yet obsolete (150) | (20) | Not known at this time. |
| References | [17] | [69] | [68] |
| Allies | Equipment suppliers. | | Modo Chemetics, Sweden |

## APPENDIX B

## EXAMPLE OF R&D PROJECT DESCRIPTION

## OUTLINE FOR TERMS OF REFERENCE

## INVESTIGATION OF RF / HOT AIR DRYING OF POLYMER PELLETS

# PROCESS APPLICATION R&D OPPORTUNITY PROJECT DESCRIPTION

## Investigation of RF / Hot Air Drying of Polymer Pellets

RATIONALE

Plastic and Synthetic resin industry ranks within the top six in all categories including, value-added, value of goods per establishment and number of establishments. Drying of polymers presents a unique challenge to conventional drying methods because of the heat sensitive nature of the product. With polymers such as PVC and butyl rubber, for example, exposure to high temperatures (190 to 260 C) can result in poor molecular weight distributions and other unsatisfactory physical properties. By utilizing hybrid RF equipment, polymers can be dried at lower temperatures resulting in higher tensile strength, higher modulus of elasticity and improved appearance [17].

By combining microwave or RF equipment with a conventional hot-air drying system, a one-third reduction in total energy for drying of polymers is possible [17]. Retrofitting a microwave/RF unit to an existing polymer hot-air dryer is also claimed to increase production rates. Another benefit is the reduction of the organic solvents, which are removed from polymers in drying, rather than being released to the environment later, in an uncontrolled fashion.

OBJECTIVE

Optimize performance of RF / hybrid drying equipment and drying schedules of moisture-sensitive polymers

SCOPE

Identify candidate Ontario-based manufacturers and establish collaboration and potential cost sharing associated with development;
Select polymers, obtain RF / hybrid prototype equipment;

| | |
|---|---|
| | Conduct laboratory evaluations (eg, material properties, energy use, equipment performance);<br>Perform field evaluation and monitor equipment performance |
| FUNDING LEVEL | Staged funding with appropriate milestones/targets/gates for project tracking |
| ESTIMATED COMPLETION | Based on project cost breakdown (to be determined) |
| DELIVERABLES | Equipment demonstration in an actual plant and possible case study |
| POTENTIAL COLLABORATORS | Society of Plastics Engineers, Plastic Institute of Canada, industrial customers (see specific regional requests) |